

HEAT EXCHANGER FOR HIGH STAGE GENERATOR OF ABSORPTION CHILLER

Background of the Invention

[0001] The invention relates in general to an absorption cooling system and more specifically to an improved heat exchanger for a high stage generator of an absorption chiller.

[0002] A direct-fired, double effect, absorption chiller/heater consists of an evaporator, absorber, condenser, high and low stage generators, separator, solution heat exchanges, refrigerant/solution pumps, burner and gas train assembly, purge, controls and auxiliaries. Water is used as the refrigerant in vessels maintained under low absolute pressure (vacuum). In the cooling mode, the chiller operates on the principle that under vacuum, water boils at a low temperature, thereby cooling the chilled water circulating through the evaporator tubes. A refrigerant pump is used to circulate the refrigerant water over the evaporator tubes to improve heat transfer.

[0003] To make the cooling process continuous, the refrigerant vapor must be removed as it is produced. To accomplish this, a lithium bromide solution (which has a high affinity for water) is used to absorb the water vapor. As this process continues, the lithium bromide becomes diluted, reducing its absorption capacity. A solution pump then transfers this weak (diluted) solution to the generators where it is reconcentrated in 2 stages to boil off the previously absorbed water.

[0004] In the high stage generator a significant amount of energy is lost in the exhaust flue gas. There has always been a continuing need in the field for improved efficiency in operating absorption chillers.

[0005] It is therefore a further object of the present invention to provide an absorption system having improved efficiency.

[0006] It is a further object of the present invention to provide an improved high stage generator for an absorption chiller.

[0007] It is another object of the present invention to provide a system which utilizes lost energy in flue gas exhaust through a system which utilizes a flue gas recuperator.

Summary of the Invention

[0008] The present invention relates to a system for recovering energy remaining in the exhaust of a high stage generator.

[0009] According to the present invention, in a standard liquid tube type high stage generator, a partition plate is positioned toward the end of the heat exchanger dividing the high and low pressures of a high and low stage of a triple or double effect absorption chiller cycle. The section from the fire tube up to the partition plate brings down the flue temperature up to approximately 650 F for a triple effect and up to 400 F for a double effect cycle. There is significant amount of energy remaining in the exhaust, which is recovered by preheating or boiling solution at a lower pressure in the remaining section of the flue passage, called flue gas recuperator (FGR). The FGR is a flooded type heat exchanger. Although the liquid tubes of both high stage generator and FGR section are shown to be of the same height, the tubes of FGR may be taller in order to reduce solution charge. The saturated (or heated) solution or solution vapor mixture goes to a conventional lower stage generator where an effect of advanced absorption cycle is materialized by generating more vapor utilizing high pressure steam generated in the high stage generator. The primary object of the invention is to modify a conventional high stage generator of a specific tonnage double effect chiller for a triple effect system. Since a triple effect chiller will have a lower gas firing rate (due to higher COP), there is virtually no change in the flue side flow length; thus the net pressure drop will be lower (due to lower flow rate). The addition of partition plate adds only marginal cost to the generator, making it economical and compact.

Brief Description of the Drawings

[0010] For a further understanding of these and objects of the invention, reference will be made to the following detailed description of the invention which is to be read in connection with the accompanying drawing, wherein:

[0011] FIG. 1 illustrates a schematic for a forward-series absorption chiller cycle.

[0012] FIG. 2 illustrates a typical forward series absorption cooling cycle with LiBr-water.

[0013] FIG. 3 illustrates a schematic of a parallel series absorption chiller cycle.

[0014] FIG. 4 illustrates a typical parallel absorption cooling cycle with LiBr-water.

[0015] FIG. 5 is a sectional view which illustrates a high stage generator modified design of the present invention.

[0016] FIGS. 6(a) and (b) are schematic illustrations tracing the heating solution leaving absorber in a flue gas recuperator of the present invention, and the corresponding T-X diagram.

[0017] FIG. 6(c) illustrates schematic options for embodiment 2.

[0018] FIGS. 7(a) and (b) are schematic illustrations utilizing a flue gas recuperator to heat bypassed solution, and the corresponding T-X diagram.

[0019] FIGS. 8(a) and (b) are schematic illustrations illustrating heating bypassed weak solution leaving heat exchanger 2, and the corresponding T-X diagram.

[0020] FIG. 9 is a sectional view which illustrates the use of a flue gas recuperator as an auxiliary generator.

[0021] FIG. 10 is a schematic illustration of the cycle using a flue gas recuperator as an auxiliary generator.

[0022] FIGS. 11(a) and (b) are schematic illustrations tracing the heating solution leaving H_2 in FGR and corresponding T-X diagram.

[0023] FIGS. 12(a) and (b) are schematic illustrations tracing the heating solution leaving the absorber in FGR in parallel to H_2 and the corresponding T-X diagram.

Detailed Description of the Invention

[0024] Figure 1 of the drawings illustrates a typical forward series absorption chiller cycle operating in cooling mode, using LiBr-water as the working fluid.

Figure 2 shows a T-X diagram for the cycle of Figure 1.

[0025] The absorption cycle can be explained as follows. Weak lithium bromide (LiBr) solution leaving absorber (A) is heated from point 1 to point 2 in a low temperature heat exchanger (H2), while cooling strong solution leaving low stage generator (G2) from point 8 to point 9. Weak solution leaving H2 is heated to point 3 in high temperature using heat to cool strong solution from point 5 to point 6. Weak solution leaving H1 is preheated to point 4 and then steam is generated to increase solution concentration to point 5 in G1. Steam generated in G1 is condensed in G2 tubes, while producing lower pressure steam in G2 shell-side, thus increasing the concentration of solution from point 7 to point 8. Processes 6-7 and 9-10 are flashing processes where superheated solution is brought into a lower pressure environment, thus producing steam as a result of isenthalpic expansion. Ideally, H1 and H2 should be designed such that there is no flashing. Figure 2 shows nominal temperatures of various state points in the absorption cycle under consideration.

[0026] Heat exchanger effectiveness of H1 and H2 are defined as the ratio of actual rate of energy transfer to theoretical maximum rate of energy transfer. This is calculated as the ratio of temperature difference of fluid stream having a lower value of $m \cdot c_p$ (where m is mass flow rate and c_p is specific heat), to the difference between entering temperature of strong and weak solution. For example, in this particular case, $m \cdot c_p$ of strong solution is lower than $m \cdot c_p$ of weak solution. Hence, the effectiveness of H1 is calculated as $\epsilon = (155-92)/(155-72) = 75.9\%$. Effectiveness of H2 is calculated as $\epsilon = (92-52)/(92-38) = 74.1\%$. Effectiveness of these heat exchangers play a key role in determining overall COP of absorption cycle.

[0027] External energy is supplied to the cycle in the G1, which is utilized in preheating solution from point 3-4 and then generating steam from point 4-5. If effectiveness of H1 and H2 is increased, then the amount of energy utilized in preheating solution from 3-4 can be minimized. However, in doing so, the

temperature of point 9 can reduce significantly to a level such that there may be a danger of crystallization of strong solution. For example, crystallization temperature of 64% solution is 38.2C. If H2 has a 95% effectiveness, the leaving temperature of point 9 would be 40.7C. Improving effectiveness of H2 would increase risk of crystallization in H2 strong solution.

[0028] In a direct fired absorption chiller, flue gas leaving G1 is at a relatively high temperature (around 190C). Considerable amount of energy can be recovered from this flue gas if utilized effectively. Figure 5 illustrates a modified G1 design that can allow such energy recovery.

[0029] The absorption cycle illustrated in Figures 3 and 4 is explained as follows. Weak solution leaving absorber (A) is split into two streams. One stream is heated from point 1 to point 2 in a low temperature heat exchanger (H2), while cooling strong solution leaving low stage generator (G2) from point 7 to point 8. Other stream leaving absorber is heated to point 3 in high temperature heat exchanger (H1), while cooling strong solution leaving high stage generator (G1) from point 5 to point 6. Weak solution leaving H1 is preheated to point 4 and then steam is generated to increase solution concentration to point 5 in G1. Steam generated in G1 is condensed in G2 tubes, while producing lower pressure steam in G2 shell-side, thus increasing concentration of solution from point 2 to point 7. Figure 1 shows nominal temperatures of various state points in the absorption cycle under consideration.

[0030] External energy is supplied to the cycle in the G1, which is utilized in preheating solution from point 3-4 and then generating steam from point 4-5. If effectiveness of H1 and H2 is increased, then the amount of energy utilized in preheating solution from 3-4 can be minimized. However, in doing so, the temperature of point 8 can reduce significantly to a level such that there may be a danger of crystallization of strong solution. For example, crystallization temperature of 64% solution is 38.2C. If we use H2 of 95% effectiveness, the leaving temperature of point 9 would be 40.7C. Improving effectiveness of H2 would increase risk of crystallization in H2 strong solution.

[0031] Figure 5 is a side sectional view of a high stage generator G1 of the present invention in which the solution side of the generator is divided into two sections 12 and 14 by a partition plate 16. Burner 18 provides a flame into the fire section 20, with the smoke section designated 22. The section on the left-hand side of the partition plate in Figure 5 is a typical configuration of G1. Flue gas leaves G1 at a high temperature (190C). It can be further cooled to a lower temperature depending on the source for low temperature solution. This section will hereinafter be identified as the flue gas recuperator (FGR). Typical G1 has 80-82% burner efficiency, which means 18-20% of available energy in fuel is wasted in the form of hot exhaust gas. If half of this waste energy is utilized in the cycle, the COP of cycle can be improved significantly. The following embodiments of the present invention illustrate the use of this modified design.

[0032] Embodiment 1: Heat solution leaving absorber (point 1)

This embodiment is illustrated in Figures 6(a) and (b). Solution leaves absorber at 38° C. As can be seen from Figure 6(a), this is the coldest point in the cycle. If half of the waste heat is utilized, the temperature of solution can be raised from 38° C to 48° C in the FGR. This will enable the use of H2 at very high effectiveness, without any danger of crystallization, because the cold-side temperature will be always higher than crystallization temperature of the solution.

[0033] Embodiment 2: Split a stream of solution leaving absorber

As shown in Figure 7(b), a fraction of total solution flow leaving the absorber is passed through the FGR. If 10% of total energy input is recovered in FGR, and 10% of solution flow rate leaving absorber is bypassed in the FGR, then temperatures as shown in Figure 7(b) can be achieved. Note that 1'-3' is the heating of solution with FGR. In this situation, the risk of crystallization is the same as the baseline case of Figure 1.

[0034] Embodiment 3: Split a stream of weak solution leaving H2

This embodiment is illustrated in Figures 8(a) and (b). It is similar to Embodiment 2, except instead of splitting a stream of solution leaving the absorber, a stream of weak solution is split leaving H2. In this case, the H2 leaving solution

temperature is still at 72° C, but the split stream is heated with the FGR to 145° C, and the rest of the solution is heated to 145C in H1. In this embodiment, 2-3 is heating carried out in H1 while 2'-3' is heating in the FGR.

[0035] In embodiments 2 and 3, weak solution entering low temperature heat exchanger (H2) or high temperature heat exchanger (H1) is heated in FGR. Heated weak solution leaving FGR is mixed with either weak solution leaving H2 or weak solution leaving H1. It is important to bring the temperature of heated solution leaving FGR in close proximity to the temperature of solution in which it is being mixed to avoid mixing losses and improve thermodynamic efficiency of absorption cycle. This can be accomplished by two methods. First method is mechanical device such as a fixed orifice or a field adjustable valve. Second method is an electronically controlled valve.

[0036] Figure 6(c) shows a scheme for embodiment 2, where heated solution from FGR is mixed with heated weak solution leaving H1. At full load, flue gas leaving high stage generator at full load is typically at 190-210C depending on efficiency of high stage generator. Weak solution leaving absorber is at typically at 38C. Assuming flue gas temperature leaving high stage generator of 200C, and assuming 80% effectiveness of FGR, temperature of flue gas leaving FGR would be 70C. For natural gas with 20% excess air, net burner efficiency can be improved from 82.4% to 88%. Knowing the amount of energy that can be recovered in FGR, the fraction of flow entering in FGR can be calculated such that temperature of solution leaving FGR and leaving H1 is equal. A FGR is then designed to recuperate desired heat with the calculated solution flow rate in the FGR. Pressure drop in weak solution flow is then calculated for parallel flow paths going through FGR and going through H2 and H1. An orifice is added in the solution line that has lower pressure drop such that pressure drops in both parallel flow paths are equalized. In the case of an electronically controlled valve, two temperature sensors are used to detect temperatures of two mixing streams. The valve position is determined by opening or closing valve such that temperatures of two mixing streams is equalized with use of a controller.

[0037] Embodiment 4: Using flue gas to generate steam in G2

It is possible to use 190C flue gas to generate steam in G2 where solution temperature is 87-92C. Figure 9 illustrates a sketch of such configuration with elements 16, 18, 20 and 22 being like elements as in Figure 5.

[0038] As shown schematically in Figure 10, part of the solution entering conventional G2 is bypassed to FGR. The FGR operates similar to G1, as thermosiphon reboiler or flooded evaporator depending on the design. Its vapor side is connected to the vapor side of conventional G2 such that both G2 and FGR operate at equal pressure. This FGR is termed as "recuperator-G2" or "auxiliary G2."

[0039] Embodiment 5

Figure 11(a) and (b) illustrates this embodiment. In this option, weak solution leaving H2 is passed through FGR. Temperature of weak solution leaving H2 is generally between 55C at minimum load to 72-80C at full load depending on the effectiveness of H2. For example, in a series cycle, heating weak solution leaving H2 from 72C to 78C in FGR can help recuperate waste heat from exhaust gas. In order to utilize this heat effectively, it is important to use H1 heat exchanger of higher effectiveness such that strong solution leaving H1 is sufficiently cooled to temperature in the absence of such FGR. The reason for doing so is to avoid excessive flashing of strong solution entering into low stage generator, a situation that can negate the purpose of using FGR for flue gas recuperation. The main advantage of this method is that temperature of heat transfer surface of FGR that is in contact with flue gas can be maintained above dew point of flue gas. Therefore, moisture condensation on heat transfer surface is avoided. This is important to avoid corrosion of heat transfer surface with flue gas condensation, and an ordinary material such as carbon steel can be used. In the case of option 1 or 2, flue gas condensation is possible, and hence special corrosion resistant alloy material such as low carbon stainless steel is necessary. Option 5, thus offers a low-cost method for flue gas recuperation.

[0040] Embodiment 6

Figure 12(a) and (b) illustrates this embodiment. This is similar to embodiment 2. In this option, solution flow circulating in the absorption cycle is split into two portions. One portion exchanges heat with strong solution in H2 while other portion exchanges heat with flue gas in FGR. The portions are determined such that temperature of weak solution leaving FGR and leaving H2 are approximately equal. These two solution streams are mixed and the mixed stream then enters high temperature heat exchanger.

[0041] While the present invention has been particularly shown and described with reference to the preferred mode as illustrated in the drawing, it will be understood by one skilled in the art that various changes in detail may be effected therein without departing from the spirit and scope of the invention as defined by the claims.